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A Service Oriented Routing Scheme for Internet of Things

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***Abstract*—Internet of Things (IoT) is being developed rapidly and applied widely in our society. A large number of network nodes with different attributes join in the network and makes the structure of the network rather complex. Traditional research about network routing concentrates on a few network attributes as routing metrics like energy and bandwidth. However, the network performance may be decreased when concentrating on one or few metrics. In this paper, a service oriented routing is proposed based on Polychromatic Sets theory. A scheme of cross-layer design and virtual nodes is applied to improve the network performance. Therefore, the network performance could be balanced on multiple metrics based on the different requirements of application. The simulation results on NS-3 prove that the scheme is effectively able to improve the performance of network when considering multiple network metrics.**

Keywords—Service Oriented Architecture; Cross-layer; Virtual Network; Polychromatic Sets; Internet of Things

I. INTRODUCTION

Internet of Things (IoT) is more than popular in modern communication networks. The Quality of Service (QoS) is an significant concern for the performance of IoT systems [1][2]. Normally, an IoT system consists of multiple types of network nodes, and, therefore, named as a heterogeneous network. The properties and performance of these nodes are always different, and the requirement of QoS is also different [3][4].

In order to integrate and interoperate these IoT devices and guarantee the QoS requirements, Service Oriented Architecture (SOA) provides a promising solution [5]. SOA is different from traditional networks that solve the node-to-node communications based on IP packets, information and services are the centric of SOA [6]. Therefore, the network architecture becomes more complex. In order to guarantee the performance, cross-layer design and virtual network are two typical methods to improve the SOA-based complex networks [7].

Cross-layer design is widely applied on the optimization of networks. The ability of hardware on physical layer significantly influences the performance of network layer, and the requirements on application layer also depend heavily on the performance of network layer. Therefore, it is important to optimize the network routing by considering the requirements based on multiple layers. For service oriented networks, the route discovery of network layer generally considers the service requirements of application layer and transport layer. At the same time, the performance of network interface layer is also considered by route discovery to choose a better route to improve QoS. Cross-layer analysis is an important feature and an improved problem in SOA [2]. In cross-layer networks, a software layer based on middleware technology is added as the interface of two layers to solve the interconnectivity of the cross-layer problem [8].

Network virtualization is a significant feature in service oriented networks. The traditional networks always solve the data transmission problem between node and node. However, the data transmission is not limited to one route in a service oriented network. Multiple routes could be built to transmit one data file. Then, the service oriented network is regarded as a virtual network. The data flow of a data file is not the same as the packet flow of one route any more. The optimization of interface and interconnectivity between virtual network and physical network needs to be solved in service oriented networks [1][9].

In this paper, by applying a cross-layer design approach, different metrics of the network are collected and considered together. Then Polychromatic Sets (PSets) theory is used to integrate the multiple dynamic metrics and virtual network is used to distribute the network for multiple services. The optimized routing by considering QoS would be discovered based on the multiple metrics integrated by PSets.

PSets theory is a compositive set method to consider the multiple metrics of network conveniently and then optimize the route discovery of networks by several extended algorithms. Some research works have been completed in [10][11]. In this paper, the multiple metrics of network in different layers are considered together by PSets based on previous work. Then the load of network is distributed to multiple concurrent requirements in a virtual network.

The main contributions of this paper include:

1. A new cross-layer SOA is proposed based on traditional TCP/IP model. Different from other research work proposed in [12][13] that a new layer is defined in the network, all the cross-layer interfaces are defined in network layer. Therefore, it is an extended model on network layer and most of the contributions of this work is on network layer.

2. A virtual network scenario is provided, and PSets is used to describe the whole scenario, especially the mapping relationship between virtual nodes and physical nodes.

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3. A PSets-based Multi-constraint Fast Routing Selection Algorithm (PMFRS) is proposed and applied to improve the legendary Ad hoc On-demand Distance Vector (AODV) routing protocol. Multiple metrics are considered in the new algorithm.

The remaining of this paper is organized as below. Section II introduces the related work. In section III, the new SOA structure is introduced. Section IV defines the service requirements of network and the virtual network. PSets is used to describe them. The proposed routing protocol and simulations are presented in section V and section VI, respectively. Conclusion is made in section VII.

II. RELATED WORK

Many work has been contributed on SOA for wireless networks. The main idea of these work is to add a service layer between the application layer and network layer, and then manage the network by a software defined middleware [12][13]. In [12] an adaptable and flexible middleware was proposed to configure the functionalities of wireless networks. An extensible and scalable SOA was proposed in [13] to deploy the network management system for large scale heterogeneous networks. All of these methods integrate the interconnection between application layer and network layer effectively, and then the network layer is able to acquire the service requirements from application layer. However, all of these work only redefines the network structure, but no routing scenario is proposed and deployed.

Large scale IoT systems are a typical heterogeneous network. In a heterogeneous network, the same node would ask the network to provide different performance based on different services. Some work in [14][15] proposed their SOA-based different paths selection algorithms for heterogeneous networks. Authors in [14] proposed an algorithm for Service Path Selection and Adaptation. Two service-oriented routing models were proposed in [15]. One is named as Cost Based Model and the cost of network is considered, the other is named as Gain Based Model and the relative value of service is considered. These papers provide the routing scenarios for different applications. However, these scenarios do not provide a variable routing schemes to match multiple different applications.

Network virtualization is a significant method to build the service oriented networks. It is possible to separate the network services and physical networks by using virtual networks, and then provide the optimized services based on network requirements [16]. Authors in [16] described the method and target of network virtualization, respectively. Different virtual network structures are defined and analyzed in these papers. However, their work did not explain the mathematical definitions and applications of virtual networks in detail, and did not provide the detailed scenario on operation either.

In some research work, only one attribute of the network is considered as a routing metric, for example, energy aware in [17]. In addition, some other research considers multiple metrics of network, for example, multiple metrics of networks are defined in detail in [18]. Psets theory is supposed to be a promising technique to consider multiple metrics of the network and thus improve the network performance. . In [10], a dynamic multiple metrics aware routing protocol was proposed and applied in heterogeneous wireless sensor networks. However, the detailed definition and analysis of network nodes have not been done yet.

III. SERVICE ORIENTED ARCHITECTURE

In this section, a SOA-based lightweight network structure is proposed. As shown in figure 1, the computer network is abstracted as three layers: service layer, network layer and network interface layer. The service layer includes the application layer and transport layer in traditional TCP/IP model. As it is different from other research work which a new layer is added to describe the service requirements of network, we integrate all the acquired service requirements to network layer based on previous work [10]. At the same time, the performance of devices on network interface layer is also integrated in network layer.

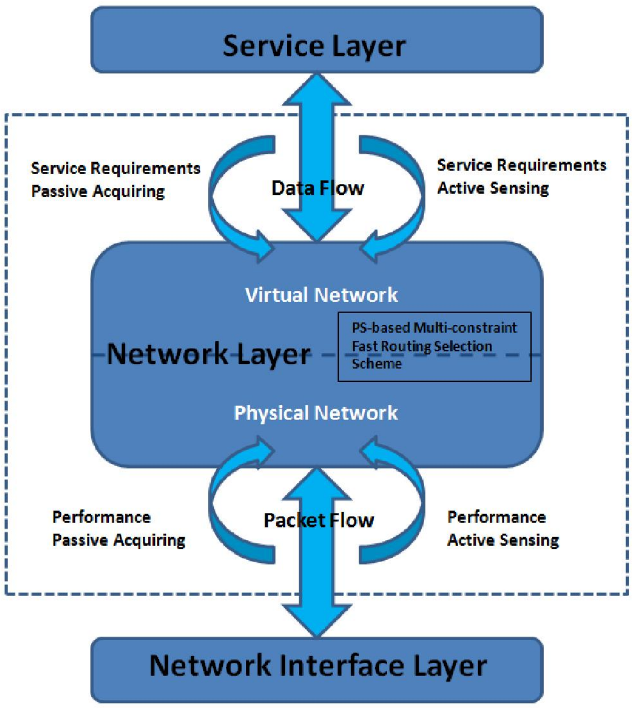

Fig. 1. A Lightweight Service Oriented Architecture

PSets is used to collect the acquired metrics after acquiring the service requirements and performance of network devices before starting the route discovery. Then an optimized routing algorithm is chosen to provide data transmission service based on the PSets-based Multi-constraint Fast Routing Selection Algorithm. The service distribution scenario is configured previously for special service requirement and performance of network devices. Details of the routing scenario are introduced in section V.

There are two ways to acquire the service requirements or performance of network devices: active sensing and passive acquiring. Active sensing is to sense the data flow or packet flow and acquire the performance based on the throughput and header information of packets, and then compare with the preconfigured threshold value to determine the level of performance. Passive acquiring is to transmit the parameters of performance to network layer directly from service layer or network interface layer. The passive way is much easier and more accurate, but there are some more work needed to be done at service layer and network interface layer.

IV. SERVICE DEFINITION

Based on PSets theory, it is convenient to integrate the complex network nodes and their properties, the service requirements on service layer and the device performance on network interface layer together. Then, the property parameters are considered by the PSets-based Multi-constraint Fast Routing Selection Algorithm and the route discovery scheme is implemented to optimize the performance of the network.

A. Dynamic Virtual Nodes

The physical network nodes are normally defined in traditional networks. In this work, a dynamic virtual network is also defined. In virtual networks, a physical network node is considered as multiple virtual nodes and provides multiple different services. One data file can also be transmitted through multiple routes based on the service requirements. Therefore, the dynamic virtual nodes are defined.

As shown in figure 2, the set of all the physical nodes GA_p is defined as:

$$GA_p = \{A_1, A_2, \cdots, A_n\} \tag{1}$$

where n is the number of physical nodes.

The set of all the virtual nodes GA_v is defined as:

$$\begin{aligned} GA_v &= \{\{a_1,a_2,a_3\},\{a_4,a_5\},\{a_3,a_6,a_7\},\cdots,\{a_{m-1},a_m\}\} \\ &= \{a_1,a_2,a_3,a_4,a_5,a_6,a_7,\cdots,a_m\} \end{aligned} \tag{2}$$

where a is a virtual node and m is the number of virtual

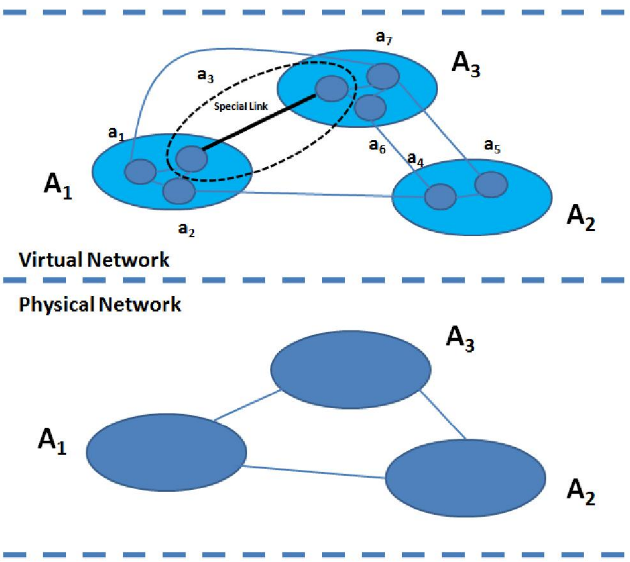

Fig. 2. Nodes in a Network

nodes, and

$$\begin{cases} A_1 = \{a_1, a_2, a_3\} \\ A_2 = \{a_4, a_5\} \\ A_3 = \{a_3, a_6, a_7\} \\ \cdots \\ A_n = \{a_{m-1}, a_m\} \end{cases} \tag{3}$$

where $a_3 \subset \{A_1, A_3\}$. There is a special link between node A_1 and A_3 to provide packet transmission service for a_3. So $a_3 \subset \{A_1, A_3\}$ is defined as $L_{a3} = \{A_1, A_3\}$.

B. Service Requirement and Physical Performance

In an IoT system, different services have different requirements. Based on the passive acquiring and active sensing of service requirements introduced in last section, the typical service types include interactive, bulk, real-time, normal, narrow-band and undefined. As shown in table I, the service requirements on capacity, jitter, delay and packet loss are listed and the priority is also given based on the experience of analysis on network requirements. The priority of service requirements can also be changed dynamically.

TABLE I. SERVICE REQUIREMENTS

Flow Type	***Capacity***	***Jitter***	***Delay***	***Packet loss***
Interactive	High	High	High	High
Bulk	High	Low	Low	Low
Real-time	Medium	High	High	High
Normal	Medium	Medium	Medium	Medium
Narrow-band	Low	Low	Low	Low
Undefined	-	-	-	-

At the same time, there are also some other physical network properties related to the performance of network. These properties are effective for balancing the overhead and load of networks, and improving the QoS of network. Therefore, the performance of physical devices is also considered and added to the set of service requirements and physical performances in the SOA-based cross-layer design. The typical physical network properties [10] includes:

1. Energy. Green wireless network is proposed to save the energy and protect the environment. In the meantime, part of the nodes in IoT systems are powered by battery and the energy is limited. Therefore, the energy consumption in routing and the residual energy of nodes are considered in this work.

2. Radio Frequency, Connectivity and Interference. In complex heterogeneous networks, different physical devices in a network are applied based on different protocols on network interface layer, like WiFi and Zigbee, and some devices are able to work on different radio frequency. Therefore, the radio frequency, connectivity and interference of links are significant factors for the network performance and they are considered in this work.

3. Activity of Nodes. Normally, the networks can work on sending, receiving, idle and sleep mode. The serious packet impact might happen if a new connection is established between the nodes working on either sending or receiving mode. It would spend longer time if the node is in sleep mode and has to be awaken. Therefore, the mode of nodes is also considered in this work.

Based on the service requirements and physical node performance introduced above, the basic network properties could be defined by PSets theory.

The set of property types $GF(GA)$ is defined as:

$$GF(GA)=\{GF_1, GF_2, \cdots, GF_l\} \tag{4}$$

The parameters of one property is defined as a set GF :

$$\begin{cases} GF_1 = \{f_1, f_2, f_3\} \\ GF_2 = \{f_4, f_5, f_6\} \\ \quad \cdots \\ GF_l = \{f_{k-1}, f_k\} \end{cases} \tag{5}$$

where l is the number of properties and k is the number of the parameters of the total properties.

Therefore, the parameter set of the total properties $GF_f(GA)$ is:

$$GF_f(GA)=\{f_1, f_2, \cdots, f_k\} \tag{6}$$

C. Network Described by PSets

The total nodes and the parameters of their properties are described by a matrix as:

$$[GA_v \times GF_f(GA_v)] = \begin{array}{c} \begin{array}{ccccc} f_1 & \cdots & f_j & \cdots & f_k \end{array} \\ \left[\begin{array}{ccccc} e_{11} & \cdots & e_{1j} & \cdots & e_{1k} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ e_{i1} & \cdots & e_{ij} & \cdots & e_{ik} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ e_{m1} & \cdots & e_{mj} & \cdots & e_{mk} \end{array}\right] \end{array} \begin{array}{c} \\ a_1 \\ \cdots \\ a_i \\ \cdots \\ a_m \end{array} \tag{7}$$

$$e_{ij} = \begin{cases} 1, & f_j \in GF_f(A_{ai}) \\ 0 \end{cases}$$

If the property parameter of one node a_i is set as f_j , the element e_{ij} in matrix (7) is set as 1; otherwise, it is set as 0.

V. Routing Scheme

The PSets-based Multi-constraint Fast Routing Selection Algorithm is proposed and presented in this section. Based on the node properties and network properties which have been defined in last section, the optimized network topology could be quickly selected for different requirements of network service, and then discover the routing based on the selected network topology.

First of all, several sets of properties are defined as:

$$\begin{cases} S_{F1} = \{f_1, f_4, f_6\} \\ S_{F2} = \{f_2, f_3, f_5\} \\ \quad \cdots \\ S_{Fn} = \{f_{k1}, f_{k2}\} \end{cases} \tag{8}$$

The property sets are sorted based on different priorities in different situations. For example, the priority is $S_{F1} > S_{F2} > \cdots > S_{Fn}$ in situation 1, and the priority is $S_{Fn} > \cdots > S_{F2} > S_{F1}$ in situation 2.

When the required set of property is S_{F1} , the corresponding nodes and the set of properties are defined as:

$$[G_A \times S_{F1}(G_A)] = \begin{array}{c} \begin{array}{ccccc} f_1 & \cdots & f_j & \cdots & f_k \end{array} \\ \left[\begin{array}{ccccc} e_{11} & \cdots & e_{1j} & \cdots & e_{1k} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ e_{i1} & \cdots & e_{ij} & \cdots & e_{ik} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ e_{m1} & \cdots & e_{mj} & \cdots & e_{mk} \end{array}\right] \end{array} \begin{array}{c} \\ a_1 \\ \cdots \\ a_i \\ \cdots \\ a_m \end{array}$$

$$e_{ij} = \begin{cases} 1, & f_j \in G_A(A_{ai}) \\ 0 \end{cases} \tag{9}$$

$$and \begin{array}{l} \forall\{f_{j1}, \cdots, f_{j2}\} \subset GF_l, \\ f_{j1} \vee \cdots \vee f_{j2} = 1 \end{array}$$

For any property type GF_l , at least one property in S_{F1} should be *True*.

The PSets-based Multi-constraint Fast Routing Selection Algorithm is shown in algorithm 1. The matrix of properties in set S_{Fn} and the corresponding nodes are quickly selected based on the selection algorithm. Then, the new network topology is built based on the selected nodes.

AODV is a typical routing protocol applied on wireless ad hoc networks. Based on the network topology selected by the PSets-based algorithm, the extended AODV routing is used to discover the routes in this work. In addition, the PSets theory has been used in location based routing in our previous work [10].

VI. Simulation

The simulation is done on NS-3. AODV is a pre-positioned routing for wireless ad hoc network in NS-3. The simulation of this work extends the existing AODV routing in NS-3. In addition, a simulation of SOA for wireless ad hoc network is proposed in paper [19], and the simulation of this work is also based on that one.

Algorithm 1 PMFRS Algorithm

Input: S_{F1}, $[GA_v \times GF_f(GA_v)]$, $GF(GA)$

Output: $[G_A \times S_{F1}(G_A)]$

initialization;

num_row=size(GA_v *);*

num_column=size(S_{F1} *);*

$[G_A \times S_{F1}(G_A)]$ *=zero(num_row, num_column);*

do

  if $f_j == f_{jSF1}$

  $[G_A \times S_{F1}(G_A)] <== f_j$ *;*

while j<k

do

  if !($\{f_{j1}, \cdots, f_{j2}\} \subset GF_l$ *&* $f_{j1} \vee \cdots \vee f_{j2} = 1$ *)*

  delete row(i);

while i<m

In this paper, two types of wireless nodes with different performance on services are applied. The ratio of each type of node is 50%. Based on traditional AODV routing, these nodes are applied randomly and the performance of these nodes are not considered. However, by applying the PSets-based routing, the high priority nodes are collected based on the requirements, and then these nodes are selected by the PMFRS algorithm. The new network topology is built based on the selected nodes and then PMFRS algorithm is applied for route discovery.

A. Delay

As shown in figure 3, the delay of network communication is shown for the networks with 10~100 random nodes, and the distance between every two nodes is 50m. By traditional AODV routing, it cannot discover the routes before overtime when the number of nodes is more than 50 in a network. When

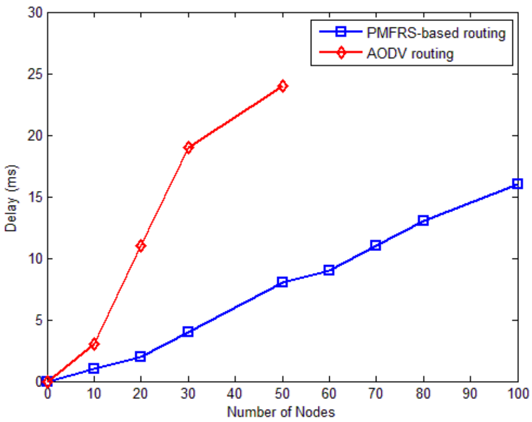

Fig. 3. Performance of delay with different number of nodes

10~50 nodes are deployed in the network, the delay increases from 3ms to 24ms rapidly. However the delay by applying the PMFRS algorithm is much lower than the traditional AODV routing , where the delay only increases from 1ms to 8ms. When the number of nodes in the network is more than 50, the network is still available to discover routes effectively. The delay is increased from 9ms to 16ms when the number of nodes increases to 100 from 50.

The PSets-based routing protocol can also improve the performance of network effectively when considering different distance between nodes when the number of nodes is fixed. In this simulation, 30 nodes are deployed in a network. As shown in figure 4, the delay in the network applying traditional AODV routing increases from 1ms to about 11ms when the nodes distance ranges from 10m to 50m. However, the delay is increased only from nearly 0 to 4ms with the same distance by applying the PSets-based routing. The delay decreases more than half in comparing with the traditional AODV routing. The PSets-based routing is possible to improve the performance of QoS effectively.

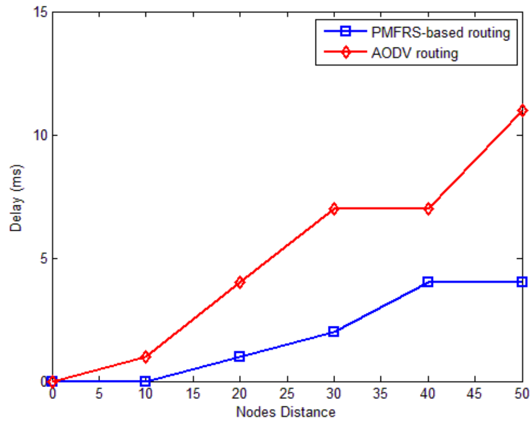

Fig. 4. Delay on Different Nodes Distance

B. Energy Consumption

The PMFRS-based routing protocol can also save energy when considering the energy consumption. As shown in figure 5, the energy consumption increases linearly following the time. The energy consumption of data transmission is a little more than 1W in traditional AODV routing. However, the energy consumption is less than 1W by PMFRS-based routing. In contrast with the traditional AODV routing, the new routing is able to choose the energy saving nodes and routes, therefore the energy consumption is decreased obviously.

A number of nodes are high energy consumption nodes in this simulation, therefore, the energy consumption in unit time increases obviously following the increasing of data packet size. As shown in figure 6, some high energy consumption nodes are applied based on traditional AODV routing. With the increasing of packet size from 100 bytes to 1000 bytes, the average energy consumption in unit time increases from about 6J to 9.5J. However, the energy consumption does not increase based on the PMFRS-based routing. Due to the new routing scheme decreasing the application of high energy

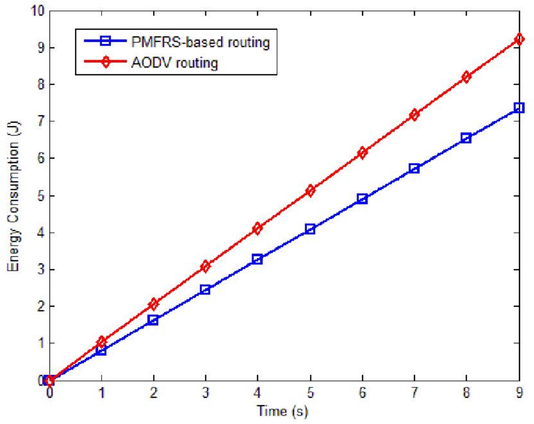

Fig. 5. Energy consumption based on time

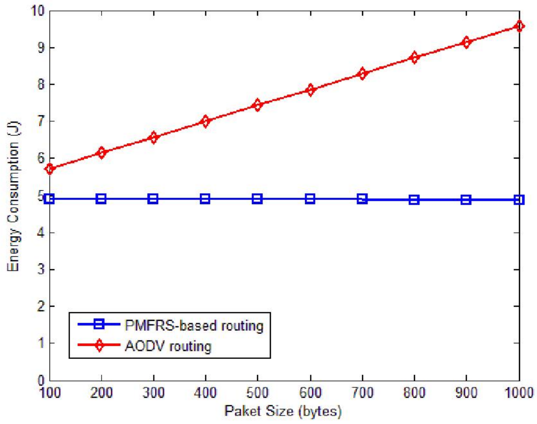

Fig. 6. Energy consumption on different packet sizes

consumption nodes effectively and most of the transmission nodes are low energy consumption nodes, the average energy consumption in unit time is always about 5J. The new routing is widely applicative in the network with different packet sizes.

VII. CONCLUSION

In this paper, a SOA-based routing scheme is proposed for IoT. This scheme is applicable for complex heterogeneous IoT systems. Cross-layer analysis and virtual networking are applied in the analysis of network, and then PSets is used to define the properties of virtual nodes and network. An extended dynamic AODV routing protocol for wireless virtual network is designed to test and verify the performance of the network in simulation. The simulation results show that the performance of network is improved in comparing with the traditional AODV routing protocol. This scheme provides a helpful idea for improving the service performance of IoT.

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